AIRPORT OBSTRUCTION SPACE MANAGEMENT USING AIRBORNE LIDAR THREE-DIMENSIONAL DIGITAL TERRAIN MAPPING

By:
Waheed Uddin
Associate Professor of Civil Engineering and Director, CAIT
The University of Mississippi
University, MS 38677-1848, USA
Voice: (662) 915-5363 Fax: (662) 915-5523 cvuddin@olemiss.edu

Emad Al-Turk
Chief Operating Officer, Waggoner Engineering Inc.
143-A LeFleurs Square, Jackson, Mississippi, 39211
Phone: (601) 355-9526 Fax: (601) 352-3945 Emad.alturk@waggonereng.com

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ABSTRACT

This paper presents an innovative application of airborne laser technology for producing three-dimensional digital terrain models and using the associated databases for evaluation and management of airport obstruction space. The airborne laser technology is a cost- effective and efficient method for creating high resolution digital terrain models and contours for civil and environmental applications. LIDAR is an acronym for **LI**ght **D**etection **A**nd **R**anging, commonly called Airborne Laser Terrain Mapping (ALTM). This paper describes the application of this remote sensing technology in conjunction with Global Positioning Systems (GPS) receivers and aerial photogrammetry for mapping airport obstruction space and approach surfaces. LIDAR provides low-altitude, high speed scanning of up to 81 sq. km (20,000 acres) per day, which permits an accuracy of 5 to 10 cm, and up to 1-ft contours. A twin-engine aircraft is used to fly the mission at an altitude of about 1,500 ft above the mean ground terrain. There are no operating constraints, such as cloud and vegetation cover, traffic and usage, or time of day, excluding aviation regulations.

The results of a recent LIDAR study funded by NASA through the Mississippi Space Commerce Initiative (MSCI) and supported by the Mississippi Department of Transportation (MDOT) are presented. The airborne LIDAR elevation data accuracy has been validated in this study with a detailed ground topographic survey conducted using standard total station equipment. The digital LIDAR database is exported to an existing geographical information system (GIS) database for further data processing such as the layout of three-dimensional obstruction space and approach surface boundaries over a runway, as required by the Federal Aviation Administration (FAA) to FAA 405 accuracy. The data can be used for establishing planimetric details and XYZ coordinates of the airport civil infrastructure assets. The digital data and obstruction space layers of the GIS can be linked with an existing comprehensive airport information management database. The use of these geospatial technologies provides a cost-effective and efficient tool to enhance airspace safety, especially for crowded airports located near urban and wooded areas.

INTRODUCTION

The safety of the aircraft and airline passengers relies heavily on the safe and efficient use of the air space in the vicinity of an airport and en route to the airport. The airport operating agency is responsible to ensure that the aerial approaches and the airfield area is adequately cleared and protected, the land in the airport restricted area is properly protected and maintained, and the construction and commercial growth in the vicinity and path of obstacle free air space is restricted through zoning ordinances. The regulations also require all high rise objects to be properly marked. Terrain topography and urban growth are important factors, which influence the efforts required by the airport operating agency to make these decisions in the most cost-effective way. Wooded and or hilly areas present special concerns and require detailed mapping surveys.

An obstacle-free navigable air space around any commercial airport is regulated by obstruction standards established by the Federal Aviation Administration through FAR Part 77 regulations (1). The obstruction chart surveys provide information critical to the safe and effective operation of the National Aerospace System (NAS). The accuracy of these charts is paramount to the safety of each and every aviator. This information is used to (2):

- Develop instrument approach and departure procedures.
- Certify airports for certain types of operations, including those conducted under Federal Aviation Regulations (FAR) Part 139 and FAR Part 77.
- Determine maximum takeoff weights for civil aircraft.
- Update official U.S. Government aeronautical publications.
- Provide geodetic control for engineering projects related to airfield construction, NAVAID site selection, obstruction clearing, road building, and other airport activities.
- Assist in airport planning and landuse studies in the airport vicinity.
- Support miscellaneous activities, such as, aircraft accident investigations and special purpose one- time projects.

A three-dimensional (3-D) map of the airfield and surrounding area provides the best visualization of obstructions defined by FAR Part 77 standards (2) for assuring a reliable and safe navigable air space. This information has traditionally been obtained with aerial imagery and conventional ground based surveying techniques, but obtaining accurate topography data, as well as obstruction identification, requires extensive on-the-ground time consuming data collection. New remote sensing aerial sensors have been developed that have better spatial and spectral resolutions than traditional aerial photography. Advances in computer hardware and software have created opportunities for improving the accuracy and efficiency of automated digital terrain models. The airborne LIDAR survey provides the best and extensive terrain mapping data. The overlaying of imaginary surface map identifies and manages all possible obstructions to air navigation. This paper specifically discusses this new and innovative application of remote sensing airborne LIDAR technology.

AIRPORT OBSTRUCTION FREE IMAGINARY SURFACES

Airport imaginary surfaces are specified to establish standards for identifying obstructions to navigable air space. These standards apply to terrain, natural-growth objects, and existing and planned manmade objects.

FAA Imaginary Surfaces for Civil Airports

The FAA imaginary surface is described in Subpart C of FAR Part 77 (1). The following civil airport imaginary surfaces are established with relation to the airport and to each runway:

(a) Horizontal surface (a horizontal plane 150 feet above the established airport elevation).
(b) Conical surface.
(c) Primary surface. A surface longitudinally centered on a runway.
(d) Approach surface.
(d) Transitional surface

Figure 1 shows a plan view, and Figure 2 shows a 3-D view of the FAA imaginary surface for civil airports. A partial longitudinal profile of a precision approach area is shown in Figure 3.

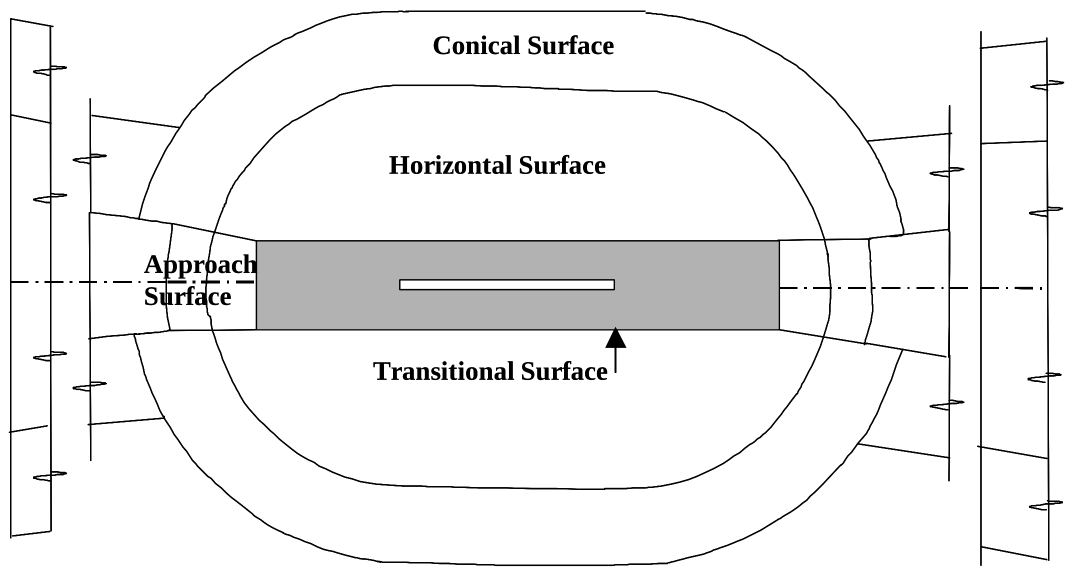

Figure 1. Plan view of FAA imaginary obstruction space standard, FAR Part 77 (3)

3-D VIEW OF FAA AIRPORT AIRSPACE CONTROL SURFACE

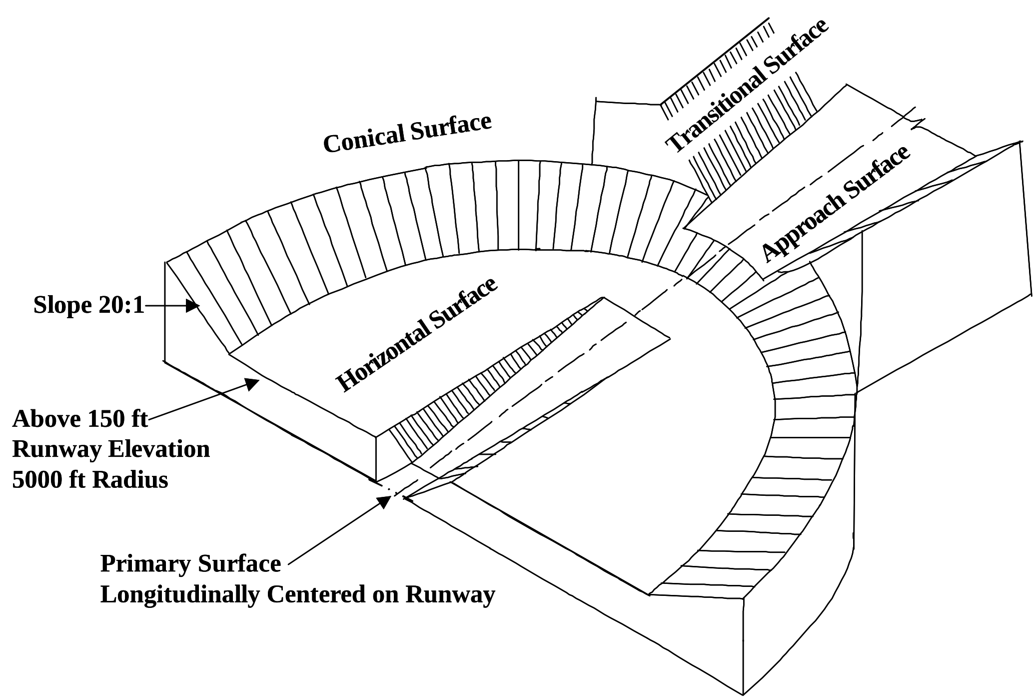

Figure 2. Isometric view of FAA imaginary obstruction space standard, FAR Part 77 (3)

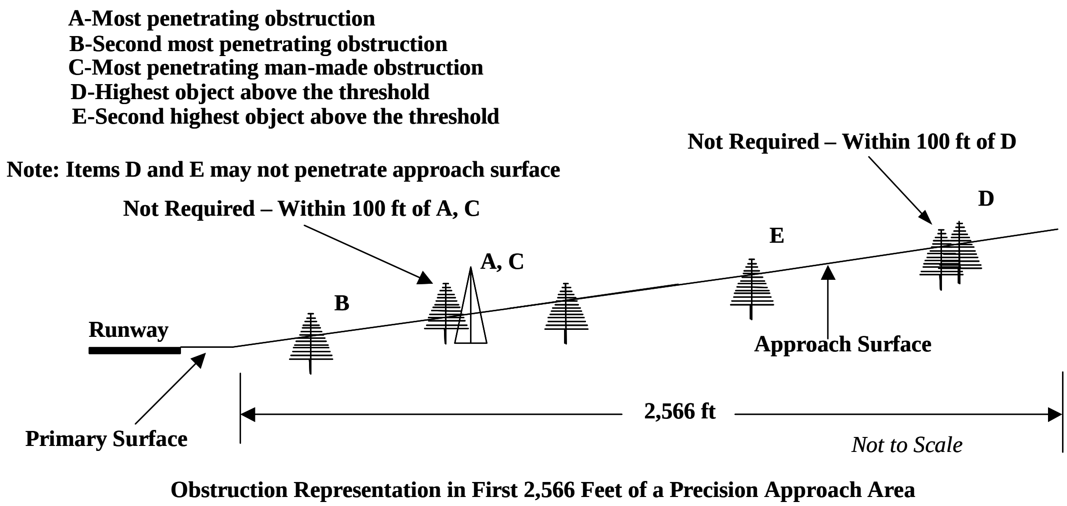

Figure 3. FAA Obstruction space standard in the precision approach area, FAA No. 405 (2)

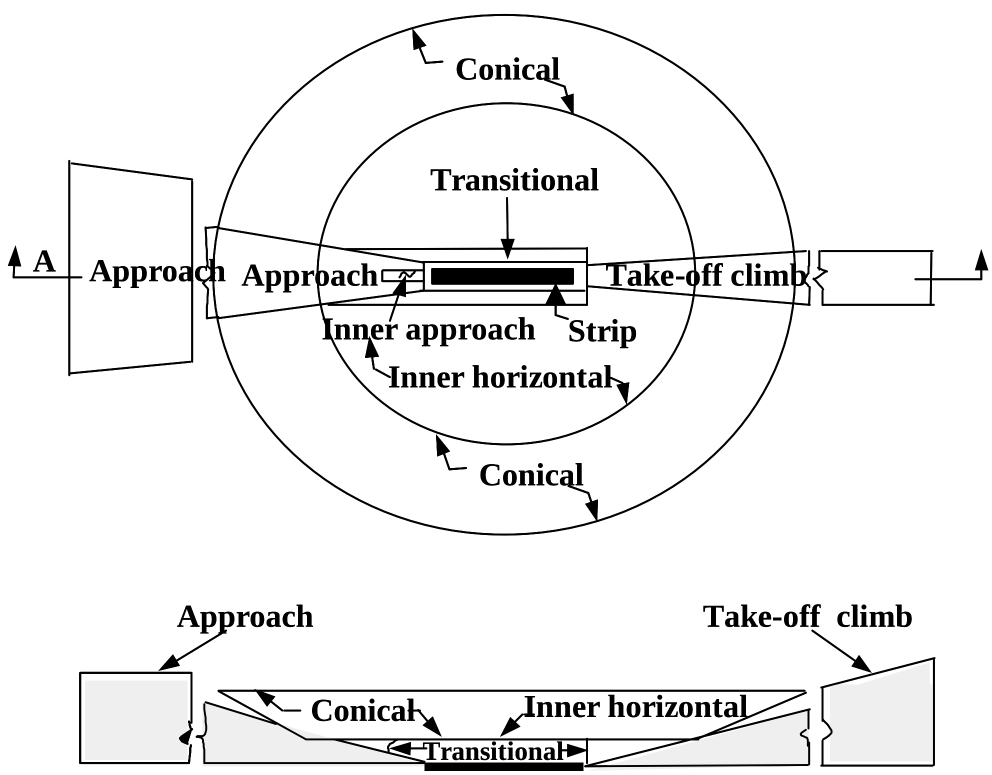

Figure 4. ICAO Imaginary obstruction limitation space standard for Aerodromes (4)

FAR part 77 imposes strict requirements on both airport sponsors and others associated with construction activities in the vicinity of airports, which should be referenced prior to initiation of construction activities. In addition to the FAA imaginary surfaces defined above, other standards (1) for determining obstructions to air navigation include: existing and future objects, whether stationary or mobile, are considered to be obstructions to air navigation if their heights are greater than any of the following heights or surfaces:

1. A height of 500 ft above ground level at the site of the object.
2. A height 200 ft above ground level or 200 ft above the established airport elevation.
3. A height within a terminal obstacle clearance area.
4. A height within an en route obstacle clearance area.
5. The surface of a takeoff and landing area of an airport or any of the imaginary surfaces.
6. Except for traverse ways on or near airport with an operative ground traffic control service furnished by the air traffic control tower or by airport management and coordinated with the air traffic control service, the heights of traverse ways must be increased by 10-23 ft for interstate highways to the height of the highest mobile object that would normally traverse it for railroads and waterways.

ICAO Imaginary Surfaces for Civil Airports

The obstruction imaginary surface, defined by the International Civil Aviation Organization (ICAO), is described in ICAO Annex 14 (4). Figure 4 illustrates the imaginary surface. The ICAO requirements are similar to FAR part 77 with the following exceptions (3). The approach surface defined in FAR part 77 is for both arriving and departing aircraft. The ICAO separates arrivals and departures and specifies dimensions for approach surfaces and takeoff climb surfaces for departures. The horizontal surface specified by ICAO is a circle whose center is at the airport reference point, whereas in FAR part 77 it is not a circle (Figure 1), nor is the airport reference point used to determine the horizontal surface. The airport reference point is the geometric centroid of the runway system at the airport based upon the lengths of the runways. The height of this surface is 150 ft above the airport elevation, as in FAR part 77. In FAR part 77 the conical surface extends horizontally 4000 ft at a slope of 20 to 1 irrespective of the type of runway and visibility. In ICAO Annex 14, the slope of the conical surface is the same, but the horizontal distance varies depending upon the aerodrome reference code (4). In FAR part 77 the slope of the transitional surface is a constant 7 to 1, whereas in ICAO Annex 14 this slope is specified for runway reference codes 3 and 4. For other runways, the slope is 5 to 1 (3).

All of the above FAA or ICAO requirements can be easily programmed to check their compliance within a 3-D surface template of the imaginary surface overlying on a densely created 3-D topographic terrain model. This is the greatest advantage offered by the 3-D terrain model generated from an airborne laser mapping survey, as described in the following sections.

LASER TECHNOLLOGY FOR TOPOGRAPHIC SURVEYS

In the United States and many parts of the world, airport and highway inventory and condition data have been collected since the last two decades at high speeds using noncontact photography, video, laser, acoustic, radar, and infrared sensors (5). Both terrestrial and traditional ground surveys can be quite hazardous. These noncontact technologies may suffer limitations due to the time of day, unavailability of airfields resulting from busy aircraft operations, traffic congestion on highways, and proximity to urban locations. The original application of laser sensors was to measure distances. Laser sensors mounted on the front bumper of a van has been primarily used to measure longitudinal profiles of highway and airfield pavements. Applications of laser profiles from a van-mounted or an aircraft-mounted equipment have been limited, due to the single line of elevation profile produced. The accuracy of measurements suffered due to navigational limitations resulting from movement of truck axle and from roll and pitch of aircraft. In recent years, the applications of LIDAR sensors have grown rapidly due to the unprecedented development in the following three technological areas:

(a) Electro-optical and mechanical systems have improved accurate and reliable control of laser scanner systems in moving aircraft.
(b) Advancement in avionics technology of inertial navigational systems and access to high resolution differential GPS receivers so that aircraft position and orientation can be continuously determined at high levels of accuracy and precision.
(c) Modern high-performance hand-held computers and microprocessors.

The main components of a LIDAR system are the laser, the scanner and projection optics, the receiver optics, and the GPS and navigational sensor system. Lasers used for topographic laser ranging typically operate in the nearinfrared (NIR) spectral band of the electromagnetic spectrum. Distances are measured by sending out pulses of light about several thousand pulses per second. A higher pulse rate can provide a wider coverage swath, higher aircraft speed, and closer spacing of elevation points on the ground. A single pulse may have multiple returns; the first return may be from tree canopy or building tops, the second from undergrowth, and the last return from bare earth. By appropriate data processing, these multiple returns are used to identify and isolate vegetation cover and buildings/structures from the bare earth terrain model. High-accuracy differential GPS receivers are used together with the aircraft avionics and several high resolution GPS ground monuments. Modern airborne noncontact LIDAR remote sensing technology offers high resolution cost-effective digital terrain mapping elevation data collection (6).

LIDAR systems directly acquire height information from both the ground and building or tree canopy simultaneously, and could provide a detailed picture of the three-dimensional characteristics of the area surrounding the airport. The capabilities of the LIDAR systems have been proven to provide automated data collection, accurate ground digital terrain models, and digital canopy replication, even in densely vegetated areas of all types of terrain. The LIDAR data have been found to be invaluable in many areas, especially where traditional methods would not be able to penetrate the canopy, or would be cost prohibitive. For example, LIDAR has been shown to provide points within a +/- 15-cm RMSE, which is the accepted National Map Accuracy Standard (NMAS) for 1-ft interval contour mapping. This accuracy level is obtained with planned point spacing less than every three feet over the mapped area. With this density and accuracy of the resultant digital terrain model and obstruction identification, coupled with a schedule that is many times as fast as the previously mentioned conventional methods for these constraints, LIDAR provides an excellent avenue for technical and economic advantages in aviation and aerospace fields.

AIRBORNE LIDAR MAPPING SURVEYS AND DIGITAL TERRAIN MODELING

Principles and Operating Protocols

The following sections provide detailed description of the LIDAR system built upon the Optech ALTM laser technology and used in the LIDAR survey projects described in this paper. Al-Turk and Uddin (5) have presented a detailed overview of the ALTM scanning head and procedures of data collection and processing. The ALTM survey relies upon extremely precise, real time aircraft positioning and highly accurate measurement of terrain characteristics. A precise airborne GPS receiver, shown in Figure 5, is used for positional accuracy of ALTM surveys. A high accuracy GPS receiver ground unit is set-up for providing ground control points. The ALTM unit records GPS positions using signals from a minimum of 12 GPS satellites, at least one time per second to obtain maximum accuracy, which is encoded on an 8 mm tape. An inertial measurement unit associated with aircraft avionics systems determines the required correction for the aircraft's roll, pitch, and heading, which is referenced to as the GPS time tag. Together, these two instruments calculate the aircraft position and orientation 50 times per second. The aircraft position and orientation are recorded at an unprecedented accuracy and reliability, within the range of a few centimeters. A twin-turbo-prop Cessna aircraft is used for ALTM missions, as shown in Figure 5 taking off from Jackson International Airport in Mississippi for one of the LIDAR missions, the Raleigh Bypass project. Most of the airport and highway application surveys are conducted at a height of 500 m (1,500 ft) above the ground level to provide maximum field coverage.

Figure 5. Propeller aircraft used for airborne LIDAR mapping

From an aircraft flying a pattern over the survey area, a focused, infrared laser (eye-safe at survey altitudes) sends up to 5,000 pulses per second to the ground. A high accuracy scanner sweeps the laser pulses across the flight path and collects the reflected light. A laser range finder, consisting of high-precision discriminators and interval meters, measures the time between sending and receiving each laser pulse to determine the ground elevation below. After precisely computing the time differential and knowing the speed of light, distances to the object are calculated. The time interval meter can either record the first return from the laser, which would be for vegetation heights, or the last return from the laser pulse, which will be potential bare ground contact.

The ALTM scanning mirror has the ability to scan back and forth from 0 to 20 degrees each side of centerline, at a frequency of 70 times per second. By varying the aircraft altitude, the aircraft speed, the scanner angle, and the scanner frequency, the operator is able to program ground point spacing to fit the particular survey mission. All this information is stored on the 8 mm tape and tied to the GPS time tags.

Flight Planning and Operating Constraints

Flight-path planning is another important factor in the LIDAR system mission. The flight path shall cover the study area satisfactorily including both parallel and enough cross flight lines to eliminate shadowing and allow for proper quality control. Unlike aerial photogrammetry, LIDAR missions can be flown without regard to sun angle. Flights may take place at night, if conditions otherwise allow. Two important factors in the LIDAR system mission planning are the point density of the randomly spaced LIDAR points and the point spacing of the uniformly spaced DEM points derived from the randomly spaced LIDAR returns. The correct point density necessary to accurately represent terrain and terrain features will depend on flight conditions, mission purpose, and required accuracy. The aircraft is generally set for flying stability at 160 km (100 miles) per hour for good data collection purposes, or flying at 296 km (185 miles) per hour for transit to and from missions. Before a flight, a ground-based GPS is set up on a known point in the survey area. Flight planning determines optimal LIDAR settings and aircraft parameters. A typical survey can collect data at a rate of up to 81 sq km (20,000 acres) per day.

An airborne platform provides non-intrusive operation, no interference with highway traffic and congestion, and no constraints on airfield operations. The LIDAR technology has few constraints typical to conventional topographic survey methods. It can survey day and night, at altitudes between 300 to 900 m (1,000 to 3,000 ft) above the ground, over any terrain, and through most vegetation and canopy. The LIDAR system tolerance for inclement weather conditions (e.g., high winds, wet snow, rain, fog, high humidity, low cloud cover) is higher than that of other photogrammetric methods. Aerial photogrammetry over wooded areas is generally conducted in winter when the trees are without leaves which is generally not a constraint on LIDAR missions. The flexibility of day and night missions is subjected to usual constraints of flying aircrafts at relatively low altitudes due to applicable aviation rules.

Processing of LIDAR Data

Following the flight, the data tapes are transferred to a ground-based computer station where a display of the recorded data is immediately made available. When the data processing of x,y,z coordinates is complete, a color-coded map is generated. In addition to randomly spaced LIDAR points, before and after removal of data associated with structures and vegetation, the contractor must produce a bare-earth digital elevation model (DEM), with the minimum regular point spacing in eastings and northings. The triangular irregular network (TIN) linear interpolation procedures are used in the development of DEM and digital terrain model.

NASA/MSCI PROJECT FOR EVALUATION OF AIRBORNE LIDAR DATA

The airborne LIDAR remote sensing digital mapping technology, in conjunction with GPS receivers and aerial photography, has been evaluated by the Center for Advanced Infrastructure Technology (CAIT) at the University of Mississippi (UM). The study is focused on an 8 km (5 mile) long highway alignment project of Raleigh Bypass near Jackson, Mississippi. The airborne LIDAR and aerial photogrammetry part of the study was funded by MSCI and NASA. The traditional ground topographic work was funded by the MDOT. The NASA/MSCI project is an evaluation of the data accuracy, efficiency, time saving, and cost-effectiveness of the airborne laser technology, compared to conventional ground based methods of terrain data acquisition.

The LIDAR survey was conducted during a two-hour flight, and all laser and GPS data were stored on one-GB 8 mm tape. The conventional topographical survey was completed in several months just for data collection because of the presence of thick forest and farmland. The immense benefit of airborne LIDAR is the speed of collecting and processing data, which has been accurately documented and validated in this first independent study of airborne LIDAR.

LIDAR Data Accuracy

Horizontal accuracy is better than 30 cm (12 in). Vertically, the LIDAR technology can be accurate within less than 15 cm (6 in). The creation of a large digital database provides both current and future benefits for mapping and other engineering applications. It is a precise update of the traditional quadrangle map parameters not previously conceivable.

In the Raleigh study, the LIDAR elevation data were also compared with the elevation data computed from the aerial photogrammetry method and the elevation data collected by conventional manual total station method. The centerline profile and 15 cross-section profiles from each of the three methods were analyzed for statistically significant differences. There is no statistically significant difference in the mean elevation data from the three methods at 95 percent confidence (6). The remote sensing data points are many times more than the manually collected data which can be used for more accurate topographic mapping, watershed modeling, and drainage analysis.

Figure 6 shows a close up view of the centerline profile of the last part of the Raleigh Bypass highway project using all three methods. The total number of ground elevation points from LIDAR and aerial photo methods are several times more than the total station survey points for the entire project length. The combined cost of the LIDAR mission, aerial photo mission, and related data processing effort is about one-third of the cost of the conventional total station survey, staking, and data processing. The combined costs of LIDAR for contour maps and ground based total station for layout and staking is almost half of the cost of the conventional total station survey without LIDAR data. Cost savings will be substantially higher for larger areas, difficult terrain, and heavily populated and congested urban areas.

GIS Applications

GIS software has the ability of displaying data in different layers. Each layer displays sorted information. So the complicated airfield and highway planning and design data can be displayed in different layers. In a conceptual design of a GIS product for airport infrastructure and obstruction space management, each layer represents one aspect of the design, and one or more attribute tables can be related to this layer to store inventory and other text information. Three-dimensional digital LIDAR coordinate data are directly loaded into terrain mapping, GIS, or CAD software. This computerized data collection and transfer leads to efficient, error-free data processing, map generation, and asset management databases. Conventional ground based topographic surveys are slow. They are limited by operating constraints and time consuming data processing.

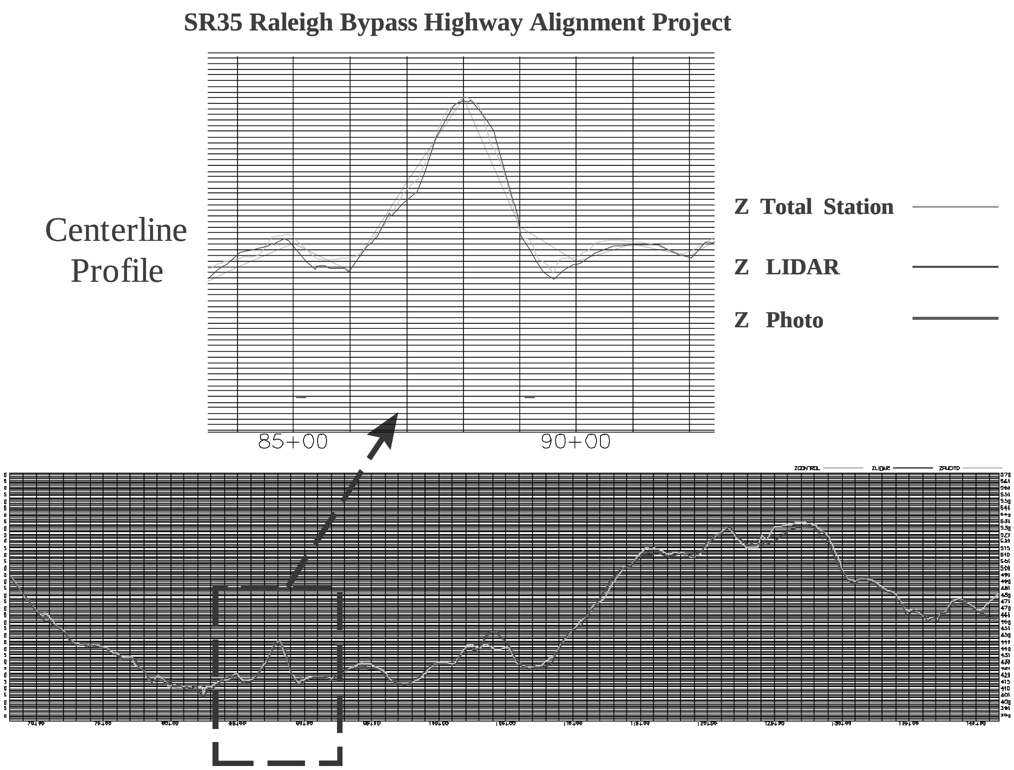

Figure 6. Comparison of centerline profiles from the three topographic survey methods

DIGITAL LIDAR TERRAIN MODEL FOR JACKSON INTERNATIONAL AIRPORT

An airborne LIDAR survey and aerial photogrammetry survey were conducted at Jackson International Airport, Mississippi in Spring 2000. The survey area covered all airport property, totaling 2,500 acres. This LIDAR application project is in direct correlation with the FAA's Standards for Aeronautical Surveys. The objectives are to use LIDAR for obtain extremely accurate 3-D digital terrain modeling in conjunction with conventional surveying techniques to develop obstruction chart surveys in a cost-effective and efficient manner as compared to the obstruction chart surveys obtained from conventional and photogrammetric methods. Data for this study needs to meet accuracy and constraints set forth by the FAA's Standards for Aeronautical Surveys. These accuracy and constraints for the obstruction chart surveys are vital for safe operations within the airspace. The point spacing to be used to achieve these constraints will necessitate sub-meter point spacing. The conventional surveying techniques will be in coordination with the same specifications set forth by FAA's Standards for Aeronautical Surveys. Figure 7 shows an example of a color-coded 3-D map section of bare-earth model for the Raleigh project after removing the vegetation cover.

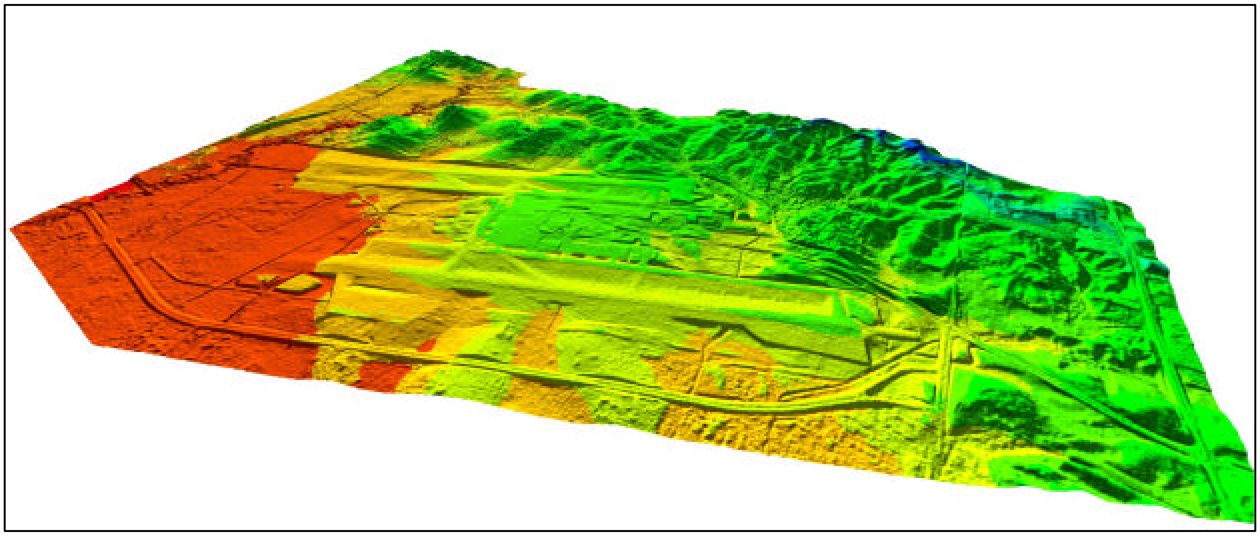

Figure 7. Three-dimensional view of processed digital LIDAR data over Jackson International Airport site, Mississippi

Typical outputs of LIDAR data post-processing include points files, contour mapping, planimetrics, and 3D visualizations and "fly-throughs." These data can be exported to different GIS layers and combined with new or stock aerial photography, and color orthorectified photo mosaics of the area. Planimetric information can be implemented using 3-D LIDAR digital terrain data and by adding new color orthophotos (to NMAS specifications). Figure 8 shows a view of contours and planimetric vector data generated for the airfield and other structures at Jackson International Airport site.

EXPECTED BENEFITS AND OUTPUTS OF LIDAR OBSTRUCTION SURVEYS

The enhanced accuracy and efficiency of using airborne LIDAR and conventional surveying combined to determine obstruction analysis versus conventional topographic surveying and photogrammetric procedures, either singularly or jointly, in an operational environment are important contributions. Traditional photogrammetric methods utilizing aerial photographs involving photo and ground plots has worked well for open areas, but does not have the accuracy or efficiency of the new sensor/image analysis technology for vegetative areas. Translating research results to acceptable operation procedures, within cost and accuracy constraints, will be the decisive factor in utilizing the new LIDAR technology.

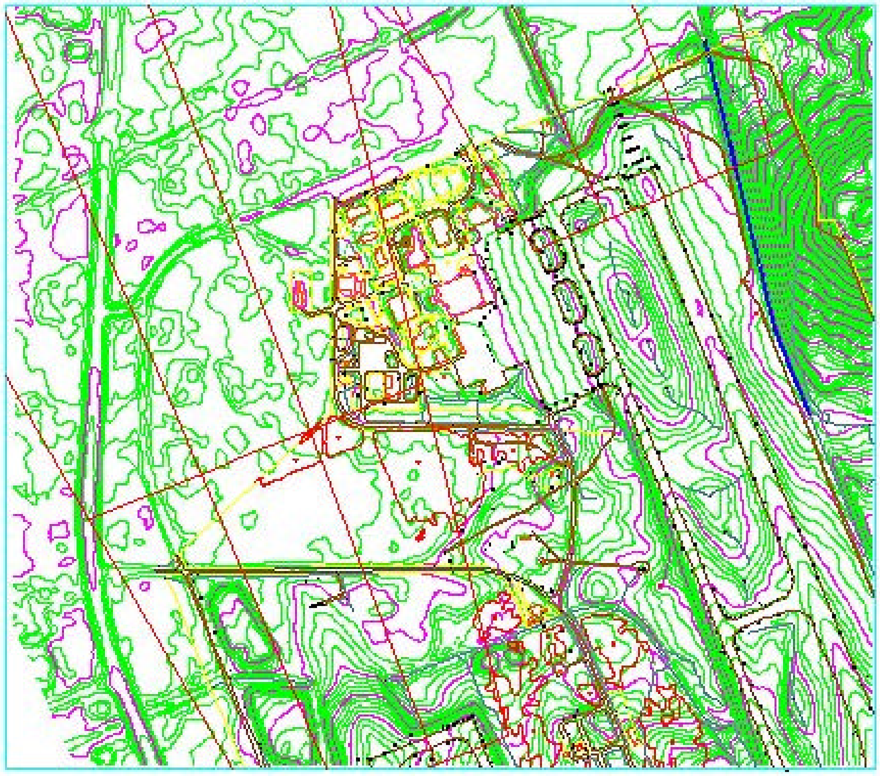

Figure 8. A view of contours and planimetric vector data generated from the digital LIDAR data

There are many additional benefits of using LIDAR/conventional surveying combination to determine the obstruction chart surveys. The data can produce a bare-earth, digital terrain model of the surveyed area to be used for future planning and design of any facilities or airport expansion, as well as drainage analysis. The canopy modeling can be used to identify those obstructions piercing through the obstruction plane today, as well as trends that will be needed to consider in the near future. All of the data collected, ground and canopy, can be easily input into an aircraft's cockpit display to give the pilots an accurate picture of the surrounding areas and the approach path to the airfield. This will identify any areas of concern with accurate three-dimensional data that can be used to safely navigate the airspace.

CONCLUDING REMARKS

The airborne LIDAR survey is technically equivalent to other technologies for FAA airport obstruction chart surveys with quantifiable savings in time and money, and it can be utilized effectively for all aerodromes in the USA. The enhanced accuracy and efficiency of airborne LIDAR can be used for producing a bare-earth digital terrain model of the surveyed area for evaluating limitations of existing airspace obstacles and for future planning and design. The three-dimensional digital database and terrain maps of the airfields and surrounding areas are valuable resources cost-effective airport asset management including planning needs for expansion and upgrading to meet the requirements of newer generation of aircraft.

Three-dimensional digital LIDAR coordinate data are directly loaded into terrain mapping, GIS, or CAD software. This computerized data collection and transfer leads to efficient, error-free data processing, map generation, and asset management databases. In essence, a template of the imaginary obstruction free surface can be constructed using the FAA FAR Part 77 or ICAO Annex standards for the a specific civil airport reference code. These templates can be made as layers of a comprehensive CAD or GIS program. This will become an important resource for efficient emergency response management in the case of natural disasters, accidents, or security concerns.

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The contents of this paper reflect the views of the authors who are solely responsible for the facts, findings, and data presented herein.

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